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UNSTEADY MHD FLOW THROUGH POROUS MEDIUM PAST A MOVING VERTICAL PERMEABLE SURFACE IN THE PRESENCE OF HEAT SOURCE AND A CHEMICAL REACTION

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ABSTRACT

An analysis is made to present unsteady flow, heat and mass transfer of an electrically conducting, viscous and heat generating / absorbing fluid through porous medium past a uniformly moving vertical permeable surface in the presence of a magnetic field and heat source considering the first order homogeneous chemical reaction and energy loss due to viscous and Joulean heat dissipations. The effects of various physical parameters on velocity, temperature and concentration profiles are shown through graphs and coefficient of skin - friction, Nusselt number and Sherwood Number are presented through tables.

KEYWORDS: MHD, Porous Media, Heat Source, Chemical Reaction, Sherwood Number

INTRODUCTION

Flow through porous media is encountered in many branches of engineering and sciences e.g. ground water hydrology, reservoir engineering, solid sciences, soil mechanics and chemical engineering etc. Recently attempts have been made to study the effects of magnetic field on an electrically conducting fluid for its various applications in MHD power generators, intercontinental ballistic missiles, confinement of plasma in nuclear fusion etc. Soundalgekar considered effects of mass transfer and free convection currents on the flow past an impulsively started vertical plate[20]. Sharma and Mathur studied the steady laminar free convection flow of an electrically conducting fluid along a porous hot vertical plate in the presence of heat source / sink[13]. Anjali devi and Kandasamy observed the effects of chemical reaction, heat and mass transfer on a laminar flow along a semi-infinite horizontal plate[3]. Unsteady two dimensional laminar flow of a viscous incompressible electrically conducting fluid in the vicinity of a semi-infinite vertical porous moving plate was discussed by Kim [11]. Das et al. reported heat transfer effects on the flow of a viscous, incompressible and electrically conducting fluid between two stretched /squeezed horizontal porous plates subject to uniform injection at upper plate in the presence of a transverse magnetic field[7]. The effects of mass transfer on unsteady MHD flow and heat transfer past an infinite vertical porous moving plate was analyzed by Sharma and Mishra [14]. Israel – Cookey et al. observed the influence of viscous dissipation and radiation on unsteady MHD free convection flow past an infinite vertical plate in an optically thin environment with time dependent suction[10]. Hydromagnetic heat and mass transfer in the flow of a viscous incompressible fluid past an infinite vertical porous plate under oscillatory suction velocity normal to the plate was discussed by Singh et al. [19]. Afify studied the effects of a chemical reaction on the free convective flow and mass transfer of a viscous, incompressible and electrically conducting fluid over a stretching surface[1]. Chen discussed the combined heat and mass transfer effect on an electrically conducting fluid in MHD natural convection adjacent to a vertical surface taking into account the effects of Ohmic heating and viscous dissipation[5]. Sharma and Mishra presented unsteady

flow and heat transfer along a porous vertical surface bounded by porous medium[18]. Sharma and Gupta discussed unsteady flow and heat transfer along a hot vertical porous plate in the presence of periodic suction and heat source[17]. Das observed the effects of constant suction and injection on MHD three dimensional Couette flow and heat transfer through porous medium[6]. Mass transfer effect on unsteady mixed convective flow and heat transfer along an infinite vertical plate bounded with porous medium was investigated by Sharma and Katta [16]. Gangadhar presented radiation and viscous dissipation effects on chemically reacting MHD boundary layer flow of heat and mass transfer through a porous vertical flat plate[8]. Sharma et al. studied mass transfer with chemical reaction in MHD convective flow along a vertical stretching sheet[15]. A sinusoidal fluid injection / suction on MHD three dimensional Couette flow through a porous medium in the presence of thermal radiation was discussed by Ahmed and Kalita [2].

The objective of the present paper is to investigate the effects of heat and mass transfer of a unsteady MHD flow of an electrically conducting, viscous and heat generating / absorbing fluid through porous medium past a uniformly moving vertical permeable surface in the presence of a heat source considering the first order homogeneous chemical reaction and energy loss due to the viscous and Joulean heat dissipations.

MATHEMATICAL ANALYSIS

Heat and mass transfer on unsteady, laminar and two dimensional incompressible flow of an electrically conducting viscous fluid through porous medium, whose surface is maintained at a uniform temperature and uniform species concentration near the wall, are considered. The surface is assumed to be infinitely long i.e. the dependent variables do not dependent on vertical or axial coordinate. The fluid flows over a continuously moving vertical permeable surface with surface suction and heat generation / absorption. A uniform transverse magnetic field is applied normal to the direction of the flow.

The magnetic Reynolds number is assumed to be small so that the induced magnetic field is neglected. The external electric field is zero and the electric field due to polarization of charges is negligible. Moreover a chemically reactive species is emitted from the moving vertical surface in hydrodynamic flow field. It diffuses into the fluid where it undergoes a simple isothermal, homogeneous chemical reaction. The reaction is assumed to take place entirely in the stream. Under these assumptions along with the Boussinesq approximation, the governing equations of unsteady flow, heat transfer and mass transfer in the presence of viscous and Joulean heat dissipation are given by

$$\frac{\partial v^*}{\partial y^*} = 0 \;\Rightarrow\; v^* \text{ is independent } of \; y^*, \tag{1}$$

$$\frac{\partial u^*}{\partial t^*} + v^* \frac{\partial u^*}{\partial y^*} = \upsilon \frac{\partial^2 u^*}{\partial y^{*2}} + g\beta(T^* - T_\infty) + g\beta(C^* - C_\infty) - \left(\frac{\sigma B_0{}^2}{\rho} + \frac{\upsilon}{K_0}\right) \tag{2}$$

$$\rho C_p \left(\frac{\partial T^*}{\partial t^*} + v^* \frac{\partial T^*}{\partial y^*}\right) = \kappa \frac{\partial^2 T^*}{\partial y^{*2}} + S^*(T^* - T_\infty) + u\left(\frac{\partial u^*}{\partial y^*}\right)^2 + \sigma B_0{}^2 u^{*2}, \tag{3}$$

$$\frac{\partial C^*}{\partial t^*} + v^* \frac{\partial C^*}{\partial y^*} = D\frac{\partial^2 C^*}{\partial y^{*2}} + \lambda^*, \tag{4}$$

where x^* is taken along the motion of the surface in upwards direction and y^* is normal to it, u^* and v^* are the velocity components along the directions of x^* and y^*, respectively, υ the kinematic viscosity, g the acceleration due to gravity, β the coefficient of thermal expansion, β^* the coefficient of concentration expansion, T^* the temperature of the fluid, T_∞ the temperature of the fluid far away from the wall, C^* the mass concentration, C_∞ the mass concentration far away from the wall, σ the electrical conductivity of the fluid, B_0 the magnetic field intensity, ρ is the fluid density, K_0 the permeability of the porous medium, κ the thermal conductivity, C_p the specific heat at constant pressure, S^* the heat source / sink parameter, μ the coefficient of viscosity, D the mass diffusion coefficient and λ^* the reaction rate term. Following Aris [4], reaction rate term λ^* represents the reaction kinetics of the system whose overall reaction is described by the power-law model given by

$$\lambda^* = -K^*(C^* - C_\infty)^n, \tag{5}$$

where K^* is the reaction rate constant and n is the order of the reaction. Hence eq. (4) is reduced to

$$v^* \frac{\partial C^*}{\partial y^*} = D\frac{\partial^2 C^*}{\partial y^{*2}} - K^*(C^* - C_\infty), \tag{6}$$

The boundary conditions are

$$\begin{aligned} &y^* = 0 \; : \; u^* = U_w, \quad v^* = -V_w(1+\varepsilon e^{i\omega t}), \quad T^* = T_w, \quad C^* = C_w \; ; \\ &y \to \infty \; : \; u^* \to 0, \; T^* \to T_\infty, \; C^* \to C_\infty . \end{aligned} \tag{7}$$

where U_w (a constant), $V_w > 0$ and T_w are the surface velocity, mean suction velocity, temperature at the wall, respectively and C_w is concentration at the wall. Solution of the equation (1) subject to equation (7) is $v^* = -V_w(1+\varepsilon e^{i\omega^* t^*})$.

Introducing the following non-dimensional quantities

$$\begin{aligned} &y = \frac{y^* V_w}{\upsilon}, \; u = \frac{u^*}{U_w}, \; \theta = \frac{T^* - T_\infty}{T_w - T_\infty}, \; C = \frac{C^* - C_\infty}{C_w - C_\infty}, \; v = \frac{v^*}{V_w}, \; t = \frac{V_w^2 t^*}{\upsilon}, \mathrm{Gr} = \frac{g\beta\upsilon(T_w - T_\infty)}{U_w V_w^2}, \\ &Gm = \frac{g\beta^*\upsilon(C_w - C_\infty)}{U_w V_w^2}, \; M = \left(\frac{\sigma B_0^2 \upsilon}{\rho V_w^2}\right)^{\frac{1}{2}}, \; S = \frac{\upsilon S^*}{\rho C_p V_w^2}, \; \omega = \frac{\upsilon w^*}{V_w^2}, K_p = \frac{K_0 V_w^2}{\upsilon^2}, \mathrm{Pr} = \frac{\mu C_p}{\kappa}, \\ &Ec = \frac{V_w^2}{C_p(T_w - T_\infty)}, \; Sc = \frac{\upsilon}{D}, \; K = \frac{K^*\upsilon}{V_w^2}, \end{aligned} \tag{8}$$

in the equations (2), (3), and (6) we get

$$\frac{\partial^2 u}{\partial y^2}-\frac{\partial u}{\partial y}-\frac{\partial u}{\partial t}+Gr\theta+GmC-\left(M^2+\frac{1}{K_p}\right)u=0, \tag{9}$$

$$\frac{\partial^2 \theta}{\partial y^2}-\Pr\frac{\partial \theta}{\partial y}-\Pr\frac{\partial \theta}{\partial t}+SPr\theta+Ec\Pr\left(\frac{\partial u}{\partial y}\right)^2+M^2Ec\Pr u^2=0, \tag{10}$$

$$\frac{\partial^2 C}{\partial y^2}-Sc\frac{\partial C}{\partial y}-Sc\frac{\partial C}{\partial t}-K\,Sc\,C=0, \tag{11}$$

where Gr the Grashof number, Gm the modified Grashof number, $\Pr$ the Prandtl nmber, Sc the Schmidt number, K chemical reaction parameter, M the Hartmann number, S heat source / sink parameter, K_p permeability parameter, Ec suction Eckert number and other physical quantities have their usual meanings.

The non-dimensional boundary conditions are given by :

$$\begin{aligned} &y=0\ :\ u=1,\ v=-(1+\varepsilon e^{i\omega t}),\ \theta=1,\ C=1;\\ &y\to\infty\ :\ u\to 0,\quad \theta\to 0,\ C\to 0. \end{aligned} \tag{12}$$

Equations (9) to (11) are coupled, non linear partial differential equations and their closed form solution cannot be determined. In the neighbourhood of the wall, velocity, temperature and concentration of the fluid can be expressed in the given form:

$$\left.\begin{aligned} &u(y,t)=u_0(y)+\varepsilon e^{i\omega t}u_1(y)+o(\varepsilon^2)+\ldots..\\ &\theta(\mathrm{y,t})=\theta_0(y)+\varepsilon e^{i\omega t}\theta_1(y)+o(\varepsilon^2)+\ldots..\\ &\mathrm{C(y,t)}=C_0(y)+\varepsilon e^{i\omega t}C_1(y)+o(\varepsilon^2)+\ldots.. \end{aligned}\right] \tag{13}$$

substituting (13) in to equations (9) to (11) and equating the harmonic and non-harmonic terms and neglecting the higher order terms of $\theta(\varepsilon)^2$, we obtain six equations for $u_0,u_1,\theta_0,\theta_1,C_0,C_1$ which are still coupled and non-linear whose exact solutions cannot be determined. Further, for incompressible fluid flows, the Eckert number is very small, therefore $u_0,u_1,\theta_0,\theta_1,C_0,C_1$ can be expanded in the power of Ec as given below

$$F(y)=F_0(y)+EcF_1(y)+O(Ec^2), \tag{14}$$

where F stands for $u_0,u_1,\theta_0,\theta_1,C_0\ or\ C_1.$

Using eq. (14) into the expression of $u_0,u_1,\theta_0,\theta_1,C_0,C_1$ and equating the terms free from Ec and coefficient of Ec , we get the following systems of ordinary differential equations:

Zeroth order equations

$$u_{00}''+u_{00}'-\left(M^2+\frac{1}{K_p}\right)u_{00}=-Gr\theta_{00}-GmC_{00}, \tag{15}$$

$$u''_{01} + u'_{01} - \left(M^2 + \frac{1}{K_p} \right) u_{01} = -Gr\theta_{01} - GmC_{01} \tag{16}$$

$$\theta''_{00} + Pr\theta'_{00} + S\,\Pr\theta_{00} = 0, \tag{17}$$

$$\theta''_{01} + \Pr\theta'_{01} + S\,\Pr\theta_{01} = -\Pr(u'_{00})^2 - M^2\,\Pr^2 u_{00}^2, \tag{18}$$

$$C''_{00} + Sc\,C'_{00} - K\,Sc\,C_{00} = 0, \tag{19}$$

$$C''_{01} + Sc\,C'_{01} - K\,Sc\,C_{01} = 0. \tag{20}$$

The corresponding boundary conditions are

$$y = 0: \; u_{00} = 1,\; u_{01} = 0,\; \theta_{00} = 1,\; \theta_{01} = 0,\; C_{00} = 1, C_{01} = 0;$$

$$y = 0: \; u_{00} = 1,\; u_{01} = 0,\; \theta_{00} = 1,\; \theta_{01} = 0,\; C_{00} = 1, C_{01} = 0;¶$$

$$y \to \infty: \; u_{00} \to 0,\; u_{01} \to 0,\; \theta_{00} \to 0,\; \theta_{01} \to 0, C_{00} \to 0, C_{01} \to 0. \tag{21}$$

First order equations

$$u''_{10} + u'_{10} - \left[i\omega + \left(M^2 + \frac{1}{K_p} \right) \right] u_{10} = -u'_{00} - Gr\theta_{10} - GmC_{10}, \tag{22}$$

$$u''_{11} + u'_{11} - \left[i\omega + \left(M^2 + \frac{1}{K_p} \right) \right] u_{11} = -u'_{01} - Gr\theta_{11} - GmC_{11}, \tag{23}$$

$$\theta''_{10} + \Pr\theta'_{10} - \Pr(S - i\omega)\theta_{10} = -\Pr\theta'_{00}, \tag{24}$$

$$\theta''_{11} + \Pr\theta'_{11} - \Pr(S - i\omega)\theta_{11} = -\Pr\theta'_{01} - 2\Pr u'_{00}u'_{10} - 2M^2\Pr u_{00}u_{10}, \tag{25}$$

$$C''_{10} + ScC'_{10} - Sc(i\omega + K)C_{10} = -ScC''_{00}, \tag{26}$$

$$C''_{11} + ScC'_{11} - Sc(i\omega + K)C_{11} = -ScC'_{01}. \tag{27}$$

The corresponding boundary conditions are

$$y = 0: \; u_{10} = 0,\; u_{11} = 0,\; \theta_{10} = 0,\; \theta_{11} = 0, C_{10} = 0,\; C_{11} = 0;$$

$$y \to \infty: \; u_{10} \to 0,\; u_{11} \to 0,\; \theta_{10} \to 0,\; \theta_{11} \to 0,\; C_{10} \to 0,\; C_{11} \to 0. \tag{28}$$

Solving equations (15) to (20) under the boundary conditions (21) and the equations (22) to (27) under the boundary conditions (28), the expressions of $u_{00}, u_{01}, \theta_{00}, \theta_{01}, C_{00}, C_{01}, u_{10}, u_{11}, \theta_{10}, \theta_{11}, C_{10}$ and C_{11} are known. Finally in view of eq. (13), the expressions of $u(y,t)$, θ (y,t) and C(y,t) are known and given by

$$
\begin{aligned}
u(y,t) = {} & [(\mathrm{B}_2\, e^{-I_4 y} - B_3 e^{-I_3 y} - B_4 e^{-I_1 y}) + Ec(B_{12} e^{-I_4 y} + B_{13} e^{-I_3 y} + B_{14} e^{-2I_4 y} + B_{15} e^{-2I_1 y} + B_{16} e^{-2I_3 y} + B_{17} e^{-H_1 y} \\
& + B_{18} e^{-H_2 y} + B_{19} e^{-H_3 y})] + \varepsilon e^{i\omega t}[(B_{21} e^{-I_6 y} + B_{22} e^{-I_2 y} + B_{23} e^{-I_1 y} + B_{24} e^{-I_5 y} + B_{25} e^{-I_3 y} + B_{26} e^{-I_4 y}) \\
& + Ec(B_{44} e^{-I_6 y} + B_{45} e^{-I_5 y} + B_{46} e^{-I_3 y} + B_{47} e^{-2I_4 y} + B_{48} e^{-2I_1 y} + B_{49} e^{-2I_3 y} + \mathrm{B}_{50} \mathrm{e}^{-H_1 y} + B_{51} e^{-H_2 y} + B_{52} e^{-H_3 y} + B_{53} e^{-H_4 y} \\
& + B_{54} e^{-H_5 y} + B_{55} e^{-H_6 y} + B_{56} e^{-H_7 y} + B_{57} e^{-H_8 y} + B_{58} e^{-H_9 y} + B_{59} e^{-H_{10} y} + B_{60} e^{-H_{11} y} + B_{61} e^{-H_{12} y}) \qquad \text{...(29)}
\end{aligned}
$$

$$
\begin{aligned}
\theta(\mathrm{y,t}) = {} & [\mathrm{e}^{-I_3 y} + Ec(B_5 e^{-I_3 y} + B_6 e^{-2I_4 y} + B_7 e^{-2I_1 y} + B_8 e^{-2I_3 y} + B_9 e^{-H_1 y} + B_{10} e^{-H_2 y} + \mathrm{B}_{11} \mathrm{e}^{-H_3 y})] \\
& + \varepsilon e^{i\omega t}[(B_{20} e^{-I_5 y} - B_{20} e^{-I_3 y}) + Ec(B_{27} e^{-I_5 y} + B_{28} e^{-I_3 y} + B_{29} e^{-2I_4 y} + B_{30} e^{-2I_5 y} + \mathrm{B}_{31} \mathrm{e}^{-2I_3 y} + B_{32} e^{-H_1 y} \\
& + B_{33} e^{-H_2 y} + B_{34} e^{-H_3 y} + B_{35} e^{-H_4 y} + \mathrm{B}_{36} \mathrm{e}^{-H_5 y} + B_{37} e^{-H_6 y} + B_{38} e^{-H_7 y} + B_{39} e^{-H_8 y} + B_{40} e^{-H_9 y} + \mathrm{B}_{41} \mathrm{e}^{-H_{10} y} \\
& + B_{42} e^{-H_{11} y} + B_{43} e^{-H_{12} y})], \qquad \text{...(30)}
\end{aligned}
$$

$$
C(y,t) = e^{-I_1 y} + \varepsilon e^{i\omega t}[-B_1 e^{-I_2 y} + B_1 e^{-I_1 y}], \qquad \text{...(31)}
$$

Skin – Friction Coefficient

Knowing the velocity field, the skin – friction coefficient at the surface is given by

$$
C_f = \frac{\tau_w}{\rho U_w V_w} = \left(\frac{\partial u}{\partial y}\right)_{y=0}; \qquad \tau_w = \mu\left(\frac{\partial u^*}{\partial y^*}\right)_{y^*=0},
$$

$$
= [B_{62} + EcB_{63}] + \varepsilon e^{i\omega t}[B_{64} + EcB_{65}]. \tag{32}
$$

Nusselt Number

Knowing the temperature field, the rate of heat transfer In terms of Nusselt number at the surface is given by

$$
Nu = \frac{q_w \nu}{(T_w - T_\infty)\kappa V_w} = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0}; \qquad q_w = -\left(\frac{\partial T^*}{\partial y^*}\right)_{y^*=0},
$$

$$
= [-\mathrm{I}_3 + EcB_{66}] + \varepsilon\, e^{i\omega t}[B_{67} + EcB_{68}]. \tag{33}
$$

Sherwood Number

Knowing the concentration field, the rate of mass transfer in terms of Sherwood number at the surface is given by

$$
Sh = \frac{m_w \upsilon}{(C_w - C_\infty) D V_w} = -\left(\frac{\partial C}{\partial y}\right)_{y=0}; \; m_w = -D\left(\frac{\partial C^*}{\partial y^*}\right)_{y^*=0}
$$

$$
= -I_1 + \varepsilon\, e^{i\omega t} B_{69}. \tag{34}
$$

Here, B_1 to B_{69}, I_1 to I_6 and H_1 to H_{12} are constants and their expressions are not given here for sake of brevity.

RESULTS AND DISCUSSIONS

To study the physical situation of the problem, we have computed the numerical values of the velocity, temperature, concentration, skin –friction coefficient, rate of heat transfer in terms of Nusselt umber and rate of mass transfer in terms of Sherwood number for different values of the physical parameters. For velocity, temperature, concentration profiles skin – friction coefficient, Nusselt number and Sherwood number, parameter ε is valued as .25, ω is valued as 5, and ωt is valued as $\pi / 3$.

It is observed from Figure 1 that fluid velocity decreases due to increase in the Hartmann number, while it increases due to increase in the Eckert number or heat source parameter. It is seen from Figure 2 that the fluid velocity decreases with increase of chemical reaction parameter, Schmidt number or Prandtl number. It is observed from Figure 3 that fluid velocity increases due to increase in permeability parameter, Grashof number or modified Grashof number. Figure 4 shows that fluid temperature increases due to increase in heat source parameter, while it decreases due to increase in chemical reaction parameter or Schmidt number. Figure 5 illustrates that fluid temperature increases due to increase in Grashof number, modified Grashof number or permeability parameter where $1 \leq K_p \leq 2$. It is seen from Figure 6 that fluid temperature increases due to increase in Eckert number, while it decreases due to increase in Prandtl number or Hartmann number. It is seen from Figure 7 that mass concentration decreases due to increase in chemical reaction parameter or Schmidt number.

It is observed from Table 1 that skin –friction coefficient increases due to increase in Grashof number, modified Grashof number, heat source parameter, Eckert number or permeability parameter, while it decreases due to increase in Hartmann number, Chemical reaction parameter, Schmidt number or Prandtl number. Nusselt number increases due to increase in Prandtl number, chemical reaction parameter or Schmidt number, while it decreases due to increase in Grashof number, modified Grashof number, Hartmann number, heat source parameter, permeability parameter or Eckert number. It is also seen from the Table 1 that Sherwood number increases due to increase in chemical reaction parameter or Schmidt number.

CONCLUSIONS

In view of the graphs and tables, the following conclusions are made:

- Magnetic field produces a drag force called Lorentz force which causes reduction in the fluid velocity.
- Buoyancy effect due to Grashof number and modified number sets a convection current which accelerates the velocity of the fluid particles.
- Fluid velocity decreases with an increase in chemical reaction parameter, Schmidt number or Prandtl number.
- The velocity increases due to increase in heat source parameter, Eckert number or permeability parameter.
- Fluid temperature increases with an increase in heat source parameter, Grashof number, modified Grashof number, permeability parameter or Eckert number.
- An increase in Hartmann number, chemical reaction parameter, Schmidt number or Prandtl number leads to decrease in fluid temperature.

- An increase in Schmidt number or chemical reaction parameter leads to decrease in mass concentration.
- Grash of number, modified Grash of number, heat source parameter, Eckert number or permeability parameter enhance the coefficient of skin - friction whereas the reverse effect is observed for Hartmann number, chemical reaction parameter, Schmidt number or Prandtl number.
- Nusselt number increases with an increase in Prandtl number, chemical reaction parameter or Schmidt number whereas it decreases with an increase in Grashof number, modified Grashof number, heat source parameter, permeability parameter, Eckert number or Hartmann number.
- Chemical reaction parameter or Schmidt number enhance the Sherwood number.

Table 1: Numerical Values of Skin-Friction Coefficient, Nusselt Number and Sherwood Number at the Surface for Various Values of Physical Parameters

Gr	Gm	M	S	K_p	Pr	Ec	K	Sc	C_f	Nu	Sh
5	2	1	0.1	1	0.71	0.01	2	0.22	2.392	0.594	0.802
10	2	1	0.1	1	0.71	0.01	2	0.22	6.15	0.5	0.802
5	1	1	0.1	1	0.71	0.01	2	0.22	1.792	0.604	0.802
5	4	1	0.1	1	0.71	0.01	2	0.22	3.602	0.571	0.802
5	2	0	0.1	1	0.71	0.01	2	0.22	4.261	0.607	0.802
5	2	5	0.1	1	0.71	0.01	2	0.22	0.07	0.593	0.802
5	2	1	0	1	0.71	0.01	2	0.22	2.129	0.734	0.802
5	2	1	0.2	1	0.71	0.01	2	0.22	3.012	0.315	0.802
5	2	1	0.1	2	0.71	0.01	2	0.22	3.236	0.573	0.802
5	2	1	0.1	4	0.71	0.01	2	0.22	3.838	0.556	0.802
5	2	1	0.1	1	1	0.01	2	0.22	1.892	0.931	0.802
5	2	1	0.1	1	5	0.01	2	0.22	- 0.154	5.551	0.802
5	2	1	0.1	1	0.71	0.02	2	0.22	2.495	0.551	0.802
5	2	1	0.1	1	0.71	0.1	2	0.22	3.316	0.207	0.802
5	2	1	0.1	1	0.71	0.01	0	0.22	3.036	0.557	0.23
5	2	1	0.1	1	0.71	0.01	1	0.22	2.546	0.589	0.61
5	2	1	0.1	1	0.71	0.01	2	0.3	2.296	0.597	0.967
5	2	1	0.1	1	0.71	0.01	2	0.6	1.828	0.603	1.495

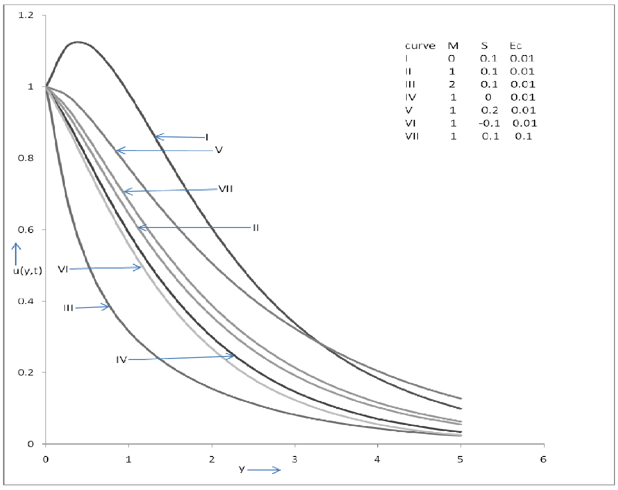

Figure 1: Velocity Profiles for Different Values of M, S and Ec, when Sc=0.22, ω =5, K=2, Gr=2, Gm=1, Pr=0.71, K_p=1, ε =0.25, and $\omega t = \pi / 3$.

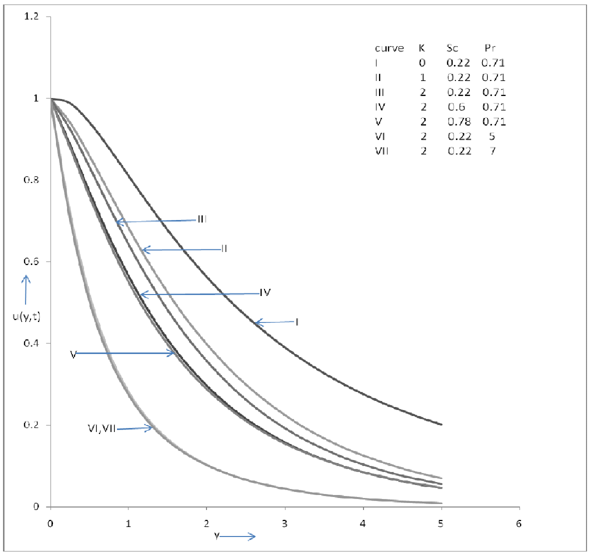

Figure 2: Velocity profiles for different values of K, Sc and Pr, when M=1, S=0.1, ω -5, K_p=1, Ec=0.01, Gr=2, Gm=1, ε =0.25 and $\omega t = \pi/3$.

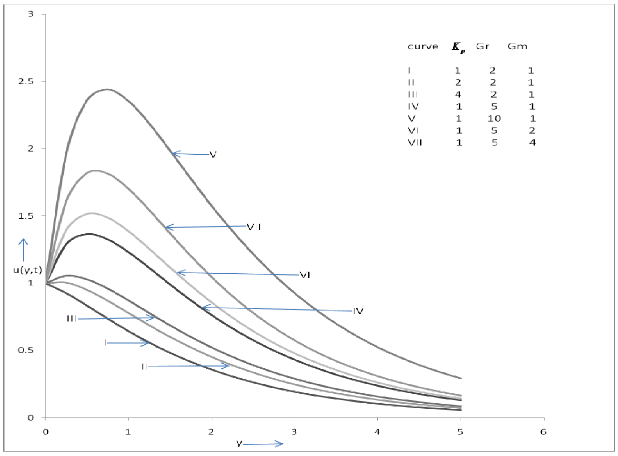

Figure 3: Velocity Profiles for Different Values of K_p, Gr and Gm, when S=0.1, ω =5, Sc=0.22, Ec=0.01, M=1, K=2, Pr=0.71, ε =0.25 and $\omega t = \pi/3$

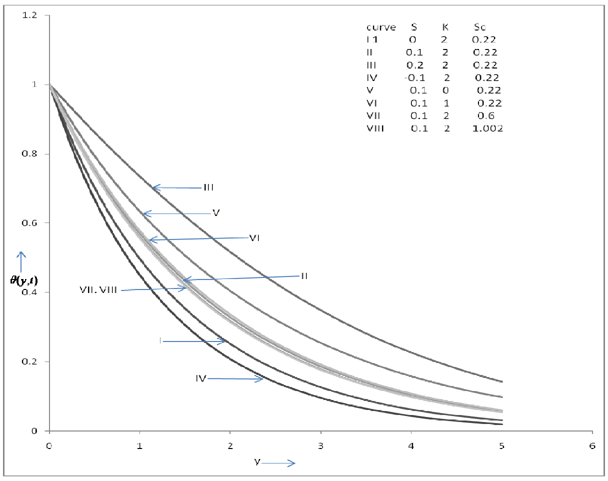

Figure 4: Temperature Profiles for Different Values of S, K and Sc, when ω =5, Ec=0.01, M=1, Gr=5, Gm=4, K_p=1, Pr=0.71, ε =0.25 and $\omega t = \pi/3$.

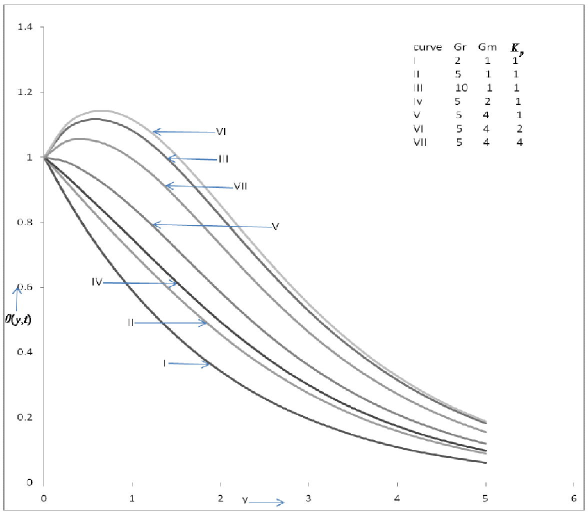

Figure 5: Temperature Profiles for different values of Gr, Gm and Kp, when S= 0.1, ω =5, K=2, Ec=0.1, m=1, Sc= 0.22, Pr=0.71, ε =0.25, $\omega t = \pi / 3$.

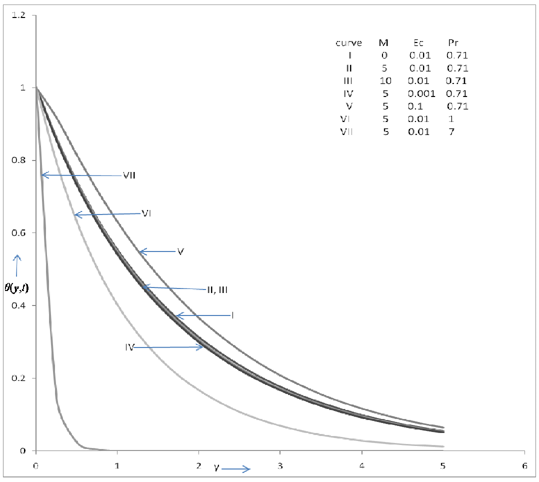

Figure 6: Temperature Profiles for Different Values of M, Ec and Pr, when S=0.1, ω=5, K=2, Gr=5, Gm=4, Sc=0. 22, K_p=1, ε=0.25 and $\omega t = \pi / 3$.

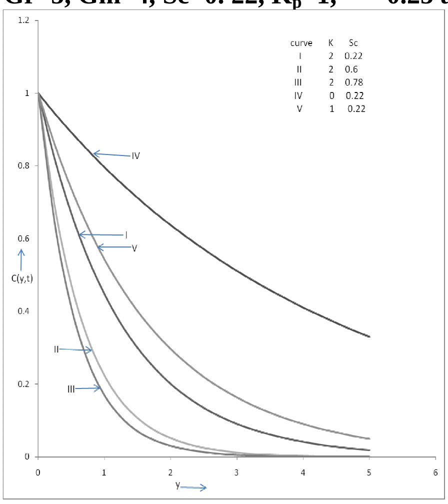

Figure 7: Concentration Profiles for Different Values of K and Sc, when S=0. 1, ω =5, Ec=0.01, Gr=2, Gm=1, M=1, K_p=1, Pr=0.71, ε =0.25 and $\omega t = \pi / 3$.

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